(51) International Patent Classification 6 : H04L 27/26	A1	(11) International Publication Number: **WO 99/30465** (43) International Publication Date: 17 June 1999 (17.06.99)

(21) International Application Number: PCT/SE98/02050

(22) International Filing Date: 13 November 1998 (13.11.98)

(30) Priority Data:
9704551–2   5 December 1997 (05.12.97)   SE

(71) Applicant *(for all designated States except US)*: TELEFON-AKTIEBOLAGET LM ERICSSON (publ) [SE/SE]; S–126 25 Stockholm (SE).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: TORE, André [SE/SE]; Guldbaggestigen 17, S–125 51 Älvsjö (SE).

(74) Agent: ERICSSON TELECOM AB; IPR Management & Patent Dept., S–126 25 Stockholm (SE).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: BIT ALLOCATION IN A TRANSMISSION SYSTEM

(57) Abstract

The present invention relates to a method for bit allocation in a multicarrier or discrete multi tone (DMT) modulated transmission system, in which a number of carriers N and a number of bits B are limited, the former due to useable frequency band and carrier spacing and the latter due to bit rate and block size. The invention comprises associating a quality factor l_j to each carrier j, $j = 1, ..., N$, computing a loading constant Lc as the quotient of a difference and the number of carriers Nr that have no bits allocated, said difference being the difference of the sum of the bit error rates l_k for carriers k, $k = 1, ..., Nr$, that have no bits allocated and the total remaining number of data bits nr that are not allocated, allocating a number of bits n_i to a carrier i that has no bits allocated, said number of bits n_i being the difference of the quality factor l_i and the loading constant Lc rounded to nearest integer, repeating the step of allocating until a predetermined fraction of the carriers k have bits allocated, and reiterating the steps of computing, allocating and repeating until all carriers j have bits allocated.

BIT ALLOCATION IN A TRANSMISSION SYSTEM

TECHNICAL FIELD OF THE INVENTION

The present invention relates to a multicarrier or discrete
multi tone (DMT) modulated transmission system, in which the
modulation may be effected using a fast inverse Fourier
5   transform (IFFT). More specifically, the invention relates to a
method for bit allocation in such a transmission system and to
the transmission system itself.

DESCRIPTION OF RELATED ART

Multicarrier modulation is a technique in which a data stream is
10   divided into several interleaved bit streams. The bit streams
are used to modulate several carriers, whereafter the modulated
carriers are summed for transmission.

Detailed descriptions of the principle of multicarrier
modulation may be found in J.A.C. Bingham, *Multicarrier*
15   *modulation for data transmission: an idea whose time has come*,
IEEE Communications Magazine, May 1990, pp. 5-14, and in
references therein.

The carriers, which are spaced within a useable frequency band,
and of which each is constituting a subchannel, are modulated at
20   a block or symbol transmission rate. The number of bits of input
data per block or symbol n_j, and the proportion γ_j of total
transmitted power P, that are allocated to each carrier or
subchannel j, are preferably determined to maximize the signal-
to-noise ratio (SNR) at a given bit rate or to maximize the bit
25   rate at a given maximally allowed overall signal-to-noise ratio
(SNR).

This is approximately achieved by choosing the variables n_j and γ_j so that the bit error rates in all subchannels are substantially equal. As a consequence, the different subchannels may transfer different number of bits per symbol and/or use

5   different transmitting powers. Various techniques have been proposed to determine the bit allocation factors n_j and the power portions γ_j at different conditions.

Through the US patent 4,438,511 (dated 1984) issued to Baran a rather simple bit rate reduction technique is known in which

10   each subchannel carries a predetermined number of bits at a specified power level. The noise at each frequency is measured and a decision is made whether to transmit or not at each carrier frequency. Thus, this technique compensates for the actual distribution of noise over the available frequency range,

15   but to the cost of a reduced bit rate.

The well known water-filling algorithm, described in e.g. J.G. Proakis, *Digital Communication*, 3rd edition, McGraw-Hill, New York, 1995 is the information theoretic method for optimizing the power distribution among the subchannels. A noise spectrum

20   is measured, i.e., the noise as a function of the frequency, whereafter available power is allocated to the subchannels in such a manner that the sum of the noise and the power is equal for all of the subchannels. The maximum number of bits to be allocated to each subchannel is then calculated from the power

25   distribution obtained and the desired bit-error-rate of each subchannel. The water-filling algorithm is, however, difficult to implement due to computational difficulties and that it may result in non-integer constellations sizes.

One implementation for constellations with integer numbers of allocated bits is described in the US patents 4,679,227, 4,731,816 and 4,833,706 (1987-1989) issued to Hughes-Hartogs. The basic principle is to incrementally add, one bit at a time, the amount of data to be transmitted in each symbol until a predetermined data rate or power constraint is reached. The subchannel to which a bit is allocated is chosen as the one who requires the least amount of incremental power at a given bit-error rate. This technique is, however, slow in convergence and assumes a time invariant signal-to-noise ratio of the subchannels.

In order to obtain faster convergence to the cost of a slightly degraded performance Chow et al. proposed another technique described in, e.g., the US patent 5,479,447 (1995). According to this technique, which may also take time-varying characteristics of the transmission medium into account and hence maintain optimal bit allocation during system operation, an initial optimal transmission rate based on initial signal-to-noise ratio estimates of the subchannels is determined. Then, the total number of bits per symbol to be transmitted in each subchannel is determined through an initial bit allocation method, in which convergence is guaranteed with a suboptimal loop. The energy distribution among the subchannels may be adjusted according to some constraint regarding the transmit power distribution. Lastly, system operation adaptivity is achieved by monitoring the subchannel noise and changing the transmission rate and/or the bit allocation within the symbol in real-time.

The main limitations with these algorithms as described is that they are too primitive (Baran) or slow and involve extended

numerical calculations and sorting (Hughes-Hartogs, Chow et al.).

Baran's algorithm does not actually allocate bits to carriers according to a changed SNR distribution among the subchannels; it merely terminates subchannels that have lower SNR than some predetermined value.

The Chow et al. algorithm with its extended numerical calculations involving, *inter alia*, a number of computationally complex steps, is best run on a microprocessor. Thus, the algorithm increases system cost and reduces speed.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method for allocating bits to carriers in a multicarrier or discrete multi tone (DMT) modulated transmission system that uses less computational power as compared with bit allocation in prior art and to provide the transmission system.

It is a further object of the invention to provide the allocating of bits to carriers at a fast rate.

It is yet a further object of the invention to provide the allocating of bits to carriers as being implemented in specific hardware.

It is still a further object of the invention to provide the allocating of bits to carriers at system startup and/or during system operation.

These objects among others are, according to one aspect of the invention, fulfilled by a method and system that comprises

following steps. A quality factor l_j is associated to each
carrier j, $j = 1, \ldots, N$. A loading constant Lc is computed as
the quotient of a difference and the number of carriers Nr that
remain to get bits allocated, said difference being the
difference of the sum of the quality factors l_k for carriers k,
$k = 1, \ldots, N$, that remain to get bits allocated and the total
number of data bits nr that remain to be allocated. Then a
number of bits n_i is allocated to a carrier i that remains to
get bits allocated, said number of bits n_i being the difference
of the quality factor l_i and the loading constant Lc rounded to
nearest integer. The step of allocating a number of bits to a
carrier is repeated for other carriers until a predetermined
fraction of the carriers that remain to get bits allocated have
bits allocated. Finally, all steps but the first (associating a
quality factor l_j to each carrier j, $j = 1, \ldots, N$) are repeated
until all carriers j have bits allocated.

However, in specific situations the difference of the quality
factor l_j and the loading constant Lc rounded to nearest
integer, i.e., the number of bits n_j that is to be allocated to
a carrier j, may be lower than zero or very high. Values lower
than zero is of course not possible to allocate and hardware
limitations often specify a maximum number of bits $nmax$ to be
allocated to a single carrier. Consequently, there is a need to
handle these kind of extreme values of n_j.

This need is, according to another aspect of the present
invention, fulfilled by a method and system that in addition to
all of the above described steps comprises the following steps.
If the number of bits n_j for any carrier j falls above $nmax$, the
quality factor l_j for that carrier/those carriers j is set to
the sum of the maximum number of bits $nmax$ and the loading

constant Lc rounded to nearest integer. If the number of bits n_j for any carrier j falls below zero, the quality factor l_j for that carrier/those carriers j is set to the value of the loading constant Lc rounded to nearest integer. Finally, if the number of bits n_j for any carrier j has fallen outside the range $[0, nmax]$ and consequently been set to a new value, all steps except the first step (associating a quality factor l_j to each carrier j, $j = 1, \ldots, N$) are repeated. This iterative procedure is continued until all carriers j have a number of bits allocated that falls inside the range $[0, nmax]$.

Preferably, the quality factor l_j, $j = 1, \ldots, N$, is related to a noise variance or an error on the corresponding carrier j. The quality factor is by preference set to the two-logarithm of the inverse of the noise variance to which an offset factor δ_j may be, but not necessarily, added.

The noise variance may be measured on a receiver side of the transmission system, e.g., as the absolute value of the difference of received signal and sent signal (or what is believed to be the sent signal).

The allocating of bits to carriers in an inventive manner may be performed at startup of the transmission system or during operation of the transmission system. In the latter case, the inventive allocating of bits may be performed if the noise changes in some manner. To discover a change in the noise, it may be measured continuously or at least on a regular basis.

The predetermined fraction of carriers to which bits are allocated before a new loading constant Lc is computed may be chosen as one half of the carriers that remain to get bits

allocated. This value facilitates hardware implementation of the invention since the division in the calculation of the loading constant may be effected by a shift operation.

An advantage of the present invention is that the bit computation is simple and rapid, thus permitting adaptive allocation of bits in real time to accommodate, for example, changing carrier conditions.

Another advantage of the invention is that the simplified procedures allows implementation using dedicated hardware for improved speed.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying Figs. 1-5 which are given by way of illustration only, and thus are not limitative of the present invention.

Fig. 1 shows a block diagram illustrating a multicarrier transmitter, a transmission link and a multicarrier receiver according to the present invention.

Fig. 2 shows a flow chart depicting an inventive bit allocation method.

Fig. 3 shows a flow chart depicting a refinement of the inventive bit allocation method.

Fig. 4 illustrates, in the frequency domain, an example of a multicarrier quality distribution and the resulting multicarrier bit allocation in accordance with the invention.

Fig. 5 illustrates, in the frequency domain, an example of a multicarrier quality distribution and the resulting multicarrier bit allocation in accordance with the refined algorithm as shown in fig. 3.

DETAILED DESCRIPTION OF EMBODIMENTS

In the following description, for purposes of explanation and not limitation, specific details are set fourth, such as particular hardware, applications, techniques, etc. in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details. In other instances, detailed descriptions of well-known methods, protocols, devices, and circuits are omitted so as not to obscure the description of the present invention with unnecessary details.

Fig. 1 shows a block diagram of an example of a DMT (Discrete Multitone) communication system that together with additional hardware and/or software may constitute a transmission system according to the present invention. A transmitter 11 includes a serial-to-parallel converter 13, a multicarrier modulator 15, and a pretransmit unit 17. A receiver 19 includes a post channel unit 21, a multicarrier demodulator 23, and a parallel-to-serial converter 25.

The transmitter and receiver are linked in this example by a digital subscriber line (DSL) 27 or other form of communication channel.

Serial input data 29 at a rate of B/T bits per second are converted to a parallel form, i.e., grouped by the converter 13

into blocks of B bits for each multicarrier symbol, with a symbol period of T. The B bits in each multicarrier symbol are used to modulate N separate carriers in the modulator 15 with n_j bits modulating the jth carrier.

A preferred example embodiment uses an inverse fast Fourier transform (IFFT) during modulation to generate N_s time-domain samples of a transmit signal for each block of B bits, where N_s is preferably equal to $2N$. The corresponding multicarrier demodulator 23 performs a fast Fourier transform (FFT), where n_j bits are recovered from the jth carrier. The carriers or subchannels in a DMT system are spaced $1/T$ Hz apart across the lower N/T Hz of the frequency band.

The serial input data that are grouped into blocks are appropriately encoded by an encoder 29. Each one of the N active subchannels contains a number of n_j bits allocated to that subchannel. The total number of bits in a DMT symbol is therefore:

$$B = \sum_{j=1}^{N} n_j$$

Each of the N bit groups is mapped into a two-dimensional signal constellation. The relation between the number of bits in each block of bits n_j and the necessary number of signal points M in a constellation is given by:

$$M = 2^{n_j}$$

Provided that the same signal energy is used for all constellations, the distance between neighboring signal points is reduced with increasing constellation sizes resulting in an

increased bit error rate (BER) with the same signal-to-noise ratio (SNR).

The output from the encoder is N complex numbers, one for each group of bits which are then fed to a device 31 that calculates the IFFT. The output is a real sequence that can be considered the superposing of N modulated orthogonal carriers spaced Δf apart.

The pre-transmit unit includes a converter 33 in which the parallel IFFT output is converted back to a serial data stream. Furthermore, during pre-transmit processing, the digital modulated data stream is cyclically prefixed, converted to analog form by a digital-to-analog converter 35, low-pass filtered, and passed through a DC isolating transformer (not shown in fig. 1) to produce an analog transmit signal that is the input to the transmission channel 27.

At receiver end, during postchannel processing, the received analog signal is passed through a DC isolating transformer and low-pass filter (not shown in fig. 1), converted to digital form by an analog-to-digital converter 37, time domain pre-equalized by a finite impulse response (FIR) filter (not shown in fig. 1) to limit the effective memory of the channel, stripped of the cyclic prefix and converted to a parallel data stream in a serial-to-parallel converter 39.

The resulting digital signals are demodulated by an FFT operation in a device 41 and converted to parallel frequency domain signals. Since the amplitude vs. frequency and the delay vs. frequency responses of the channel are not necessarily constant across the entire used frequency band, the received

signal will differ from the transmitted signal, and the parallel inputs to a decoder 43 will differ from those parallel outputs from the encoder 29. A simple form of equalization used to compensate these differences is a frequency domain equalizer (FEQ) (not shown in fig. 1), which individually adjusts for the attenuation and delay of each of the carriers immediately before the parallel frequency domain signals are passed to the decoder 43 for decoding. Lastly, the data streams are converted back to a serial output data stream 45 by the parallel-to-serial converter 25. Ideally, the detected output serial data from the decoder 43 will be identical to the input serial data to the encoder 29.

Further details regarding multicarrier modulation may be found for instance in the Bingham article, in *Discrete Multiple Tone Modulation with Coset Coding for the Spectrally Shaped Channel*, IEEE Transactions on Communications, Vol. 40, No. 6, pp. 1012-1029, June 1992 by A Ruiz et al. and in the Chow patent. These documents are hereby incorporated by reference.

The bitloading method allocates bits to be transmitted in such a way that each subchannel satisfies the demands on probability of a symbol error, P_M, within a system performance margin. The bit allocation is based on a noise variance σ^2, in each subchannel and prior knowledge of the average energy in each subchannel constellation, which together effectively provide the signal-to-noise ratio SNR for each subchannel.

According to J.G. Proakis, *Digital Communications*, 3rd edition, McGraw-Hill, New York (1995), the symbol error probability P_M for a rectangular constellation in Additive Gaussian Noise (AWGN) is tightly upper bounded by:

$$P_M \leq 4Q\left(\sqrt{\frac{3\varepsilon_{av}}{(M-1)N_0}}\right)$$

where a number of constellation points M per subchannel is defined as $M = 2^n$; $n = 1, 2, \ldots$, is the number of bits conveyed per each signal point in the constellation; ε_{av} is the average energy of the subchannel constellation and is a known design parameter set for each subchannel constellation; and N_0 is the single-sided power spectral density of the noise for a received signal constellation point (at the receiver) and is defined as $N_0 = 2\sigma^2$, where σ^2 is the received noise variance per real/imaginary dimension. The noise variance can be visualized (in a simplified manner) as the variance of the symbol error, i.e., between the signal point received and the closest constellation signal point in the complex plane. The Q function relates the signal-to-noise ratio to the symbol error P_M for a particular constellation size.

Even though the symbol error probability P_M and the bit error rate (BER) are not identical, this analysis assumes that P_M and BER are approximately the same because one symbol usually corresponds to one or more bits. Certain symbol encoding techniques, i.e., Gray coding where adjacent symbols containing the most likely errors only differ by one bit, may be employed to ensure that the bit error probability and the symbol error probability are very similar.

In most practical applications, the bit error rate (and in this application the symbol error rate P_M) is a known system design constraint. To achieve the same BER (or P_M) for all subchannel signal constellations and thereby optimally allocate bits to

each subchannel under a constraint that the average energy of all subchannel constellations is the same, the denominator $(M-1)N_0$ of the above equation must be maintained constant, i.e.,

$$(M-1)N_0 = 2\sigma^2(2^n-1) = C$$

5   The constant C depends on the specific BER to be achieved. Solving the equation for the number of bits to be allocated, n, provides the number of bits that may be assigned to a subchannel given a certain BER and the noise variance σ_j^2 on that particular subchannel, i.e., the bit allocation for each

10   subchannel j corresponding to n_j:

$$n_j = \log_2\left(1 + \frac{C}{2\sigma_j^2}\right)$$

where σ_j^2 is the noise variance on subchannel j and C is:

$$C = 3\varepsilon_{av}\left[Q^{-1}\left(\frac{P_M}{4}\right)\right]^{-2}$$

In a particular implementation, the bit loading values are

15   distributed proportional to the inverse of $\log_2$ of the noise variance σ_j^2 on the corresponding channel or carrier j. The values are limited to integer constellations, e.g., by rounding them to integer constellation sizes which affects the total number of allocated bits.

20   In the following and with reference to Figs. 1 and 2, a detailed depiction of the bit allocation method in accordance with the present invention is presented.

The inventive method may be initiated 101 by defining 103 the values of the total number of carriers N and the total number of bits B to be allocated and preferably also a maximum number of bits $nmax$ that is allowed to be allocated to a single carrier.

5   A number of variables are introduced and initially given a value 105. A variable specifying the number of carriers Nr that remain to get bits allocated is set to N. Another variable nr, that specifies the number of data bits that remain to be allocated to carriers, is initially set to B. Furthermore, two variables m

10   and k are set to zero.

A quality factor l_j is then determined 107 for each carrier j, j, $j = 1, \ldots, N$, where N is the total number of carriers. The quality factor l_j is related to the noise or error on the corresponding carrier j, $j = 1, \ldots, N$.

15   Preferably, the quality factor l_j, $j = 1, \ldots, N$, is set to the two-logarithm of the inverse of the received noise variance σ^2. To this value an offset factor δ_j may be, but not necessarily, added. The noise variance σ^2 may be measured on a receiver side of the transmission system, e.g., as the absolute value of the

20   difference of received signal and sent signal (or what is believed to be the sent signal).

The variable m is incremented 109 by one:

$m = m + 1$

whereafter a loading constant Lc is computed 111 as the quotient

25   of a difference and the number of carriers Nr that remain to get bits allocated, said difference being the difference of the sum of the quality factors l_k for carriers k, $k = 1, \ldots, Nr$, that

remain to get bits allocated and the total number of data bits *nr* that remain to be allocated, i.e.:

$$Lc = \frac{\sum_{x=N-Nr+1}^{N} l_x - nr}{Nr}$$

Then, *k* is incremented 113 by one:

5   k = k + 1

The number of bits n_k to be allocated to carrier *k* is now calculated 115 as:

$n_k = INT(l_k - Lc)$

The value of n_k must be rounded to nearest integer as only an
10   integer number of bits may be allocated to a carrier. Then, the number of carriers *Nr* that remain to get bits allocated is decreased 117 by one:

Nr = Nr - 1

and the number of remaining data bits *nr* to be allocated is
15   reduced 118 according to:

$nr = nr - n_k$

It is checked 119 whether

$Nr > N / 2^m$

and if that is the case the steps 113 through 118 is repeated
20   until *Nr* is equal to $N / 2^m$. The predetermined fraction $N / 2^m$ of carriers to which bits are allocated before a new loading constant *Lc* is computed 111, is chosen as one half of the

carriers that remain to get bits allocated. This value
facilitates hardware implementation of the invention since the
division in the calculation of the loading constant may be
effected by a shift operation. However, theoretically, the
5   fraction may be set to other values, e.g., one fourth of the
carriers that remain to get bits allocated.

The reason for recalculating a new value of Lc when half the
remaining carriers has got bits allocated is to avoid error
accumulation. This means that a new value of Lc will be
10   calculated when remaining carriers to allocate is N, $N/2$, $N/4$,
..., 4, 2, 1. This guarantees that all bits will be allocated.

Finally, it is checked 121 whether Nr is higher than 1, i.e. if:

$Nr > 1$

If Nr is higher than 1, the steps 109 trough 119 is repeated
15   until the condition no longer holds. At this point only one
carrier remains to get bits allocated. This is achieved by
incrementing 123 k by one and by computing 125 n_k as:

$n_k = B - nr$

whereafter the inventive procedure is terminated 127. The steps
20   109-125 are referred to as procedure 129 in the following of the
description. In this description it is assumed that the total
number of carriers N may be written in the form 2^x, x being an
integer. If other number of carriers are to be used the method
has to be slightly modified regarding, e.g., the predetermined
25   fraction $N / 2^m$.

In specific situations the difference of the quality factor l_j
and the loading constant Lc rounded to nearest integer, i.e.,

the number of bits n_j that is to be allocated to a carrier j, may be computed to be lower than zero or very high. Values lower than zero is of course not possible to allocate and hardware limitations often specify a maximum number of bits $nmax$ to be

5   allocated to a single carrier. Consequently, there is a need to handle these kind of extreme values of n_j.

This need is realized by another version of the present invention, which includes a refinement. This version will now be described in detail in connection with Fig. 3, which shows a

10 flow chart depicting the refined method.

The method is initiated 131. Then it follows the procedure 129 (steps 109-125) described above, after which a variable x is set 133 to "TRUE" and a variable y is set 135 to zero and then incremented 137 by one, i.e.:

15 $x =$ "$TRUE$" (step 133)

$y = 0$ (step 135)

$y = y + 1$ (step 137)

Then, it is checked 139 whether

$n_y > nmax$

20 and if so the quality factor l_y for that carrier y has to be recalculated 141 as

$l_y = Lc + nmax$

If n_y is not higher than $nmax$ it is controlled 143 if

$n_y < 0$

and if n_y is less than zero the quality factor l_y is recalculated 145 as

$$l_y = Lc$$

If n_y is recalculated according to step 141 or 145, the variable x is set 146 to "FALSE". After this step 146 or if

$$0 \leq n_y \leq nmax$$

it is checked 147 if y equals the total number of carriers:

$$y = N \ ?$$

If this is not true the steps 137-146 are repeated, i.e., it is checked for each carrier y, $y = 1,..., N$, if the number of bits allocated to it falls above $nmax$ or below zero. The quality factor l_y for that carrier/those carriers is recomputed.

It is then checked 149 if

$$x = \text{``TRUE''}$$

i.e., if no quality factor has been recomputed. If so, the inventive method is terminated 151. Otherwise, the complete set of procedures are repeated, i.e., procedure 129 and steps 133-147 until the x variable is kept as "TRUE" through one whole iteration.

Alternatively, procedure 129 and steps 133-147 are repeated a predetermined number of times (3-30) in order to achieve a simpler implementation. The number of iterations has thus to be specified in such a manner that extreme values of n_y, $y = 1,...,$ N, are eliminated.

Figs. 4 and 5 illustrate, in the frequency domain, examples of a multicarrier quality distribution and the resulting multicarrier bit allocation in accordance with the present invention. The quality distribution l (in arbitrary units) vs carrier number j is an assumed smooth curve and the bit allocation n (in number of bits) vs carrier number is a stepwise function. The number of total carriers N is 1024 and the total number of bits B in a symbol is 6000.

Fig. 4 shows a bit allocation result without any limitations of a maximum number of bits that may be allocated to a single carrier. Fig. 5 shows the result when the refined method has been used ($nmax = 12$).

The allocating of bits to carriers in an inventive manner may be performed at startup of the transmission system or during operation of the transmission system. In the latter case, the inventive allocating of bits may be performed if the noise changes in some manner. To discover a change in the noise, it may be measured continuously or at least on a regular basis.

An advantage of the invention is that the bit computation in this way permits adaptive allocation of bits in real time to accommodate, for example, changing carrier conditions.

Another advantage of the invention is that the simplified procedures allows implementation using dedicated hardware (instead of software) for improved speed.

The present invention may, of course, be applied to any communications application that employs multicarrier modulation. One example application in addition to wireline DSL applications is transmission in radio frequency bands.

The invention being thus described, it will be obvious that the same may be varied in a plurality of ways. Such variations are not to be regarded as a departure from the scope of the invention. All such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the appended claims.

CLAIMS

1. A method for allocating bits to carriers in a multicarrier or discrete multi tone (DMT) modulated transmission system, wherein a number of carriers N and a number of bits B are limited, the former due to useable frequency band and carrier spacing and the latter due to bit rate and block size, c h a r a c t e r i z e d b y the steps of:

(i) associating a quality factor l_j to each carrier j, $j = 1, \ldots, N$,

(ii) computing a loading constant Lc as the quotient of a difference and the number of carriers Nr that remain to get bits allocated, said difference being the difference of the sum of the quality factors l_k for carriers k, $k = 1, \ldots, Nr$, that remain to get bits allocated and the total number of data bits nr that remain to be allocated,

(iii) allocating a number of bits n_i to a carrier i that remains to get bits allocated, said number of bits n_i being the difference of the quality factor l_i and the loading constant Lc rounded to nearest integer,

(iv) repeating the step of allocating until a predetermined fraction of the carriers k, $k = 1, \ldots, Nr$, have bits allocated, and

(v) repeating the steps (ii)-(iv) until all carriers j have bits allocated.

2. The method as claimed in claim 1, further c h a r a c t e r i z e d b y the steps of:

(vi) in the event that the number of bits n_j for any carrier j falling above the range $[0, nmax]$, $nmax$ being a predetermined maximum number of bits to be allocated to a single carrier,

setting the quality factor l_j for that carrier/those carriers j to the sum of the maximum number of bits $nmax$ and the loading constant Lc,

(vii) in the event that the number of bits n_j for any carrier j
5   falling below the range $[0, nmax]$ setting the quality factor l_j for that carrier/those carriers j to equal the loading constant Lc, and

(viii) in the event that the number of bits n_j for any carrier j falling outside the range $[0, nmax]$ repeating the steps (ii)-
10   (vii).

3. The method as claimed in claim 1 or 2, c h a r a c t e r i z e d b y setting the quality factor l_j, $j = 1, ..., N$, to the two-logarithm of the inverse of the noise variance on the corresponding carrier j, $j = 1, ..., N$, prior to performing step
15   (ii).

4. The method as claimed in claim 1 or 2, c h a r a c t e r i z e d b y setting the quality factor l_j, $j = 1, ..., N$, to the sum of the two-logarithm of the inverse of the noise variance on the corresponding carrier j, $j = 1, ..., N$, and an offset factor δ_j,
20   $j = 1, ..., N$, prior to performing step (ii).

5. The method as claimed in claim 3 or 4, c h a r a c t e r i z e d b y measuring the noise n_j, $j = 1, ..., N$, on a receiver side of the transmission system.

6. The method as claimed in claim 5, c h a r a c t e r i z e d b y
25   measuring the noise n_j, $j = 1, ..., N$, as the absolute value of the difference of received signal and sent signal or what is believed to be the sent signal.

7. The method as claimed in claims 5 or 6, c h a r a c t e r i z e d
b y   being performed during operation of the transmission
system.

8. The method as claimed in claim 7, c h a r a c t e r i z e d   b y
being performed in the event that the noise n_j, $j = 1,..., N$,
changes in some manner.

9.   The   method   as   claimed   in   any   of   claims   1-6,
c h a r a c t e r i z e d   b y   being performed at startup of the
transmission system.

10.   The   method   as   claimed   in   any   of   claims   1-9,
c h a r a c t e r i z e d   b y   choosing one half, 1/2, as the
predetermined fraction of the carriers k.

11.   The   method   as   claimed   in   any   of   claims   1-9,
c h a r a c t e r i z e d   b y   choosing one fourth, 1/4, as the
predetermined fraction of the carriers k.

12. A multicarrier or discrete multi tone (DMT) modulated
transmission system, wherein a number of carriers N and a number
of bits B are limited, the former due to useable frequency band
and carrier spacing and the latter due to bit rate and block
size, c h a r a c t e r i z e d   b y
(i) means for associating a quality factor l_j to each carrier j,
$j = 1,..., N$,
(ii) means for computing a loading constant Lc as the quotient
of a difference and the number of carriers Nr that remain to get
bits allocated, said difference being the difference of the sum
of the quality factors l_k for carriers k, $k = 1,..., Nr$, that
remain to get bits allocated and the total number of data bits
nr that remain to be allocated,

(iii) means for allocating a number of bits n_i to a carrier i that remains to get bits allocated, said number of bits n_i being the difference of the quality factor l_i and the loading constant Lc rounded to nearest integer,

5   (iv) means for repeating the step of allocating until a predetermined fraction of the carriers k, $k = 1, ..., Nr$, have bits allocated, and

(v) means for repeating the steps (ii)-(iv) until all carriers j have bits allocated.

10   13. The multicarrier transmission system as claimed in claim 12, c h a r a c t e r i z e d   b y

(vi) means for, in the event that the number of bits n_j for any carrier j falling above the range $[0, nmax]$, $nmax$ being a predetermined maximum number of bits to be allocated to a single

15   carrier, setting the quality factor l_j for that carrier/those carriers j to the sum of the maximum number of bits $nmax$ and the loading constant Lc,

(vii) means for, in the event that the number of bits n_j for any carrier j falling below the range $[0, nmax]$, setting the quality

20   factor l_j for that carrier/those carriers j to equal the loading constant Lc, and

(viii) means for, in the event that the number of bits n_j for any carrier j falling outside the range $[0, nmax]$, repeating the steps (ii)-(vii).
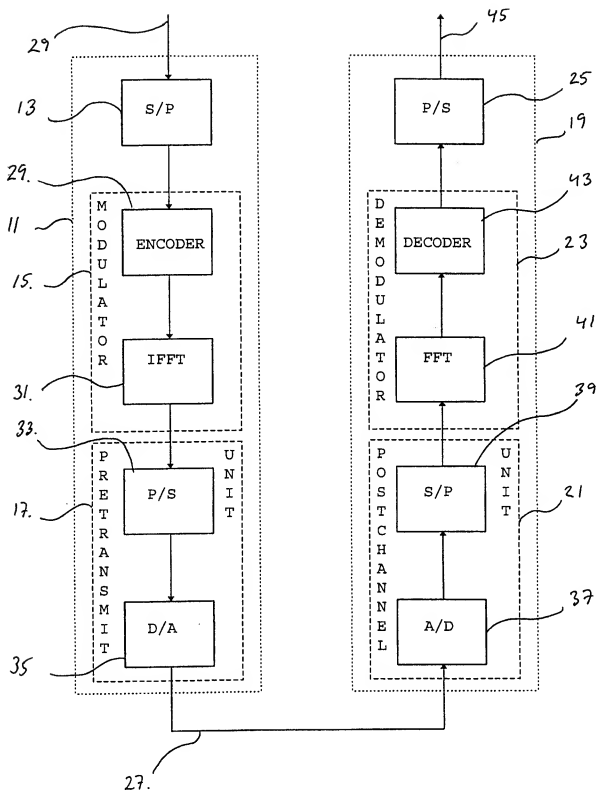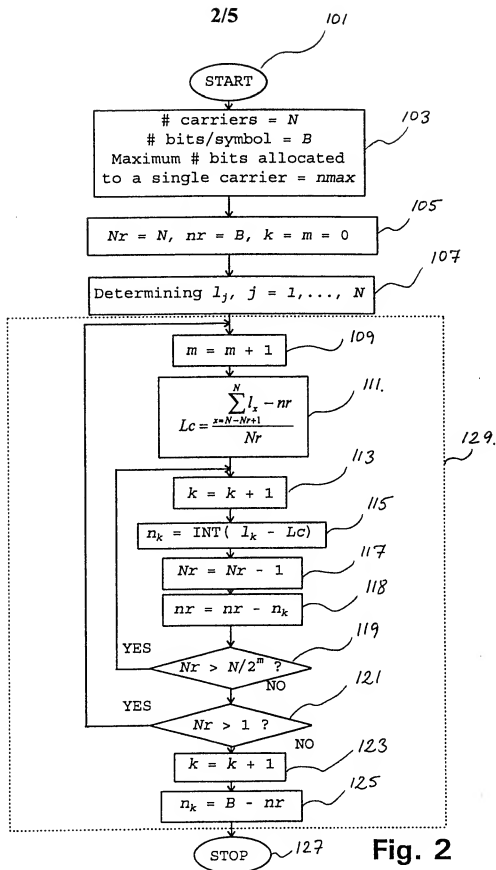
Fig. 1

2/5

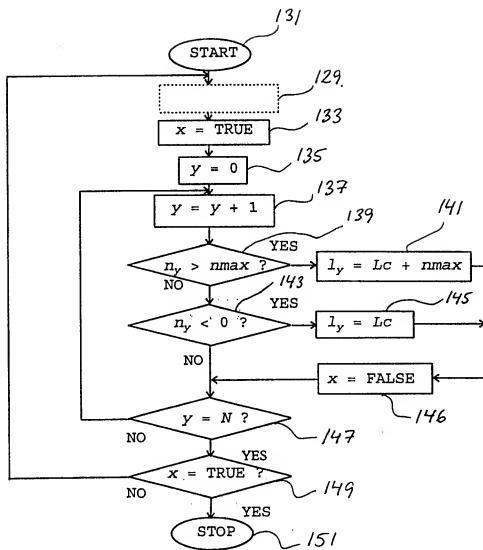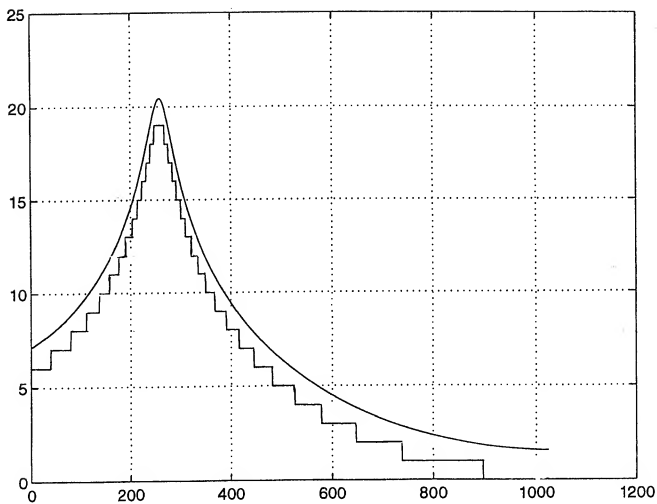Fig. 2

Fig. 3

Fig. 4

Fig. 5

INTERNATIONAL SEARCH REPORT

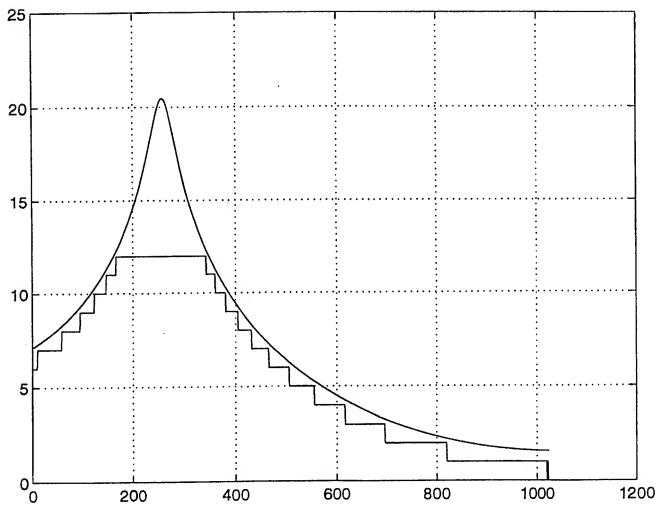|	
International application No.	PCT/SE 98/02050

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H04L 27/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5479447 A (PETER S. CHOW ET AL), 26 December 1995 (26.12.95), cited in the application --	1-13
A	US 4833706 A (DIRK HUGES-HARTOGS), 23 May 1989 (23.05.89), cited in the applications --	1-13
A	US 4731816 A (DIRK HUGES-HARTOGS), 15 March 1988 (15.03.88), cited in the applications --	1-13
A	US 4679227 A (DIRK HUGES-HARTOGS), 7 July 1987 (07.07.87), cited in the applications -- ---------	1-13

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 May 1999	1 7 -05- 1999
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. + 46 8 666 02 86	Authorized officer Bengt Romedahl Telephone No. + 46 8 782 25 00

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5479447 A	26/12/95	NONE	
US 4833706 A	23/05/89	US 4731816 A	15/03/88
		AU 587037 B	03/08/89
		AU 609355 B	26/04/91
		AU 3528189 A	21/09/89
		AU 5817786 A	24/12/86
		AU 6009690 A	15/11/90
		BR 8606677 A	11/08/87
		CA 1251586 A	21/03/89
		CN 1011461 B	30/01/91
		CN 1016556 B	06/05/92
		CN 1017296 B	01/07/92
		CN 1048774 A	23/01/91
		CN 1048775 A	23/01/91
		CN 1048776 A	23/01/91
		DE 3681887 A	14/11/91
		DK 31087 A	20/01/87
		EP 0224556 A,B	10/06/87
		SE 0224556 T3	
		JP 6003956 B	12/01/94
		JP 62502932 T	19/11/87
		PT 82600 B	29/07/94
		US 4679227 A	07/07/87
		US 5054034 A	01/10/91
		WO 8607223 A	04/12/86

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US 4731816 A	15/03/88	US	4833706 A	23/05/89
		AU	587037 B	03/08/89
		AU	609355 B	26/04/91
		AU	3528189 A	21/09/89
		AU	5817786 A	24/12/86
		AU	6009690 A	15/11/90
		BR	8606677 A	11/08/87
		CA	1251586 A	21/03/89
		CN	1011461 B	30/01/91
		CN	1016556 B	06/05/92
		CN	1017296 B	01/07/92
		CN	1048774 A	23/01/91
		CN	1048775 A	23/01/91
		CN	1048776 A	23/01/91
		DE	3681887 A	14/11/91
		DK	31087 A	20/01/87
		EP	0224556 A,B	10/06/87
		SE	0224556 T3	
		JP	6003956 B	12/01/94
		JP	62502932 T	19/11/87
		PT	82600 B	29/07/94
		US	4679227 A	07/07/87
		US	5054034 A	01/10/91
		WO	8607223 A	04/12/86

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US 4679227 A	07/07/87	AU	587037 B	03/08/89
		AU	609355 B	26/04/91
		AU	3528189 A	21/09/89
		AU	5817786 A	24/12/86
		AU	6009690 A	15/11/90
		BR	8606677 A	11/08/87
		CA	1251586 A	21/03/89
		CN	1011461 B	30/01/91
		CN	1016556 B	06/05/92
		CN	1017296 B	01/07/92
		CN	1048774 A	23/01/91
		CN	1048775 A	23/01/91
		CN	1048776 A	23/01/91
		DE	3681887 A	14/11/91
		DK	31087 A	20/01/87
		EP	0224556 A,B	10/06/87
		SE	0224556 T3	
		JP	6003956 B	12/01/94
		JP	62502932 T	19/11/87
		PT	82600 B	29/07/94
		US	4731816 A	15/03/88
		US	4833706 A	23/05/89
		US	5054034 A	01/10/91
		WO	8607223 A	04/12/86